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### **Simulation framework and case study for the design and optimisation of a combined renewable electricity and heating system with battery and thermal energy storage**

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# **Simulation framework and case study for the design and optimisation of a combined renewable electricity and heating system with battery and thermal energy storage**

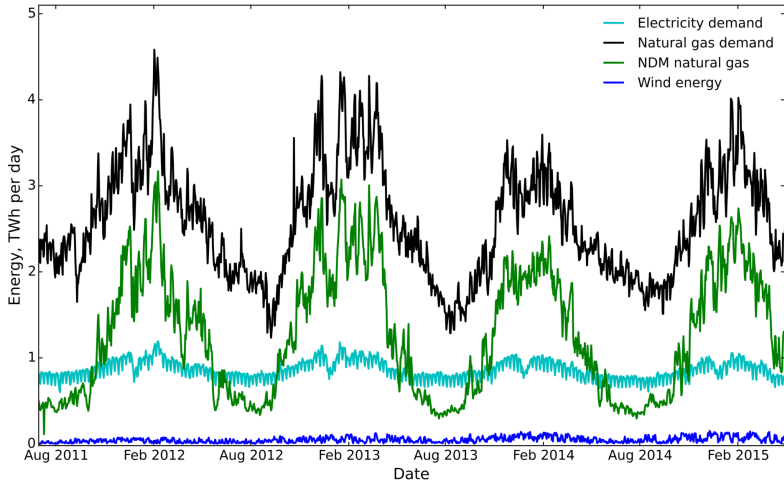
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Institute for Energy Systems  
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UK Energy Storage Conference 2015  
University of Birmingham

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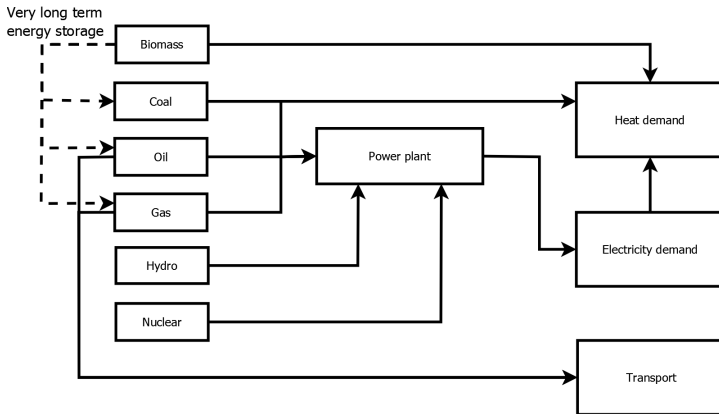
# The case for combining heating and electricity



Data from National Grid and <http://www.gridwatch.templar.co.uk>

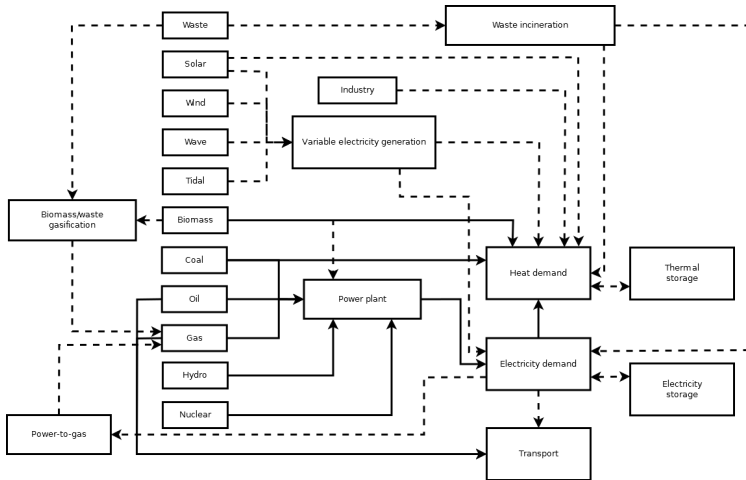


# Conventional energy system



- Dispatchable generation supplies flexibility to match electricity/heat demand and supply
- Little interaction between heat and electricity systems

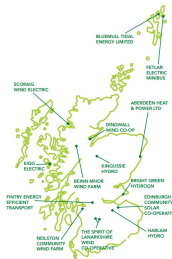
# Integrated energy system



- 1 Add storage, electricity and heat, to provide flexibility
- 2 Combine different demands and supplies to reduce variation

## Energy system for remote locations

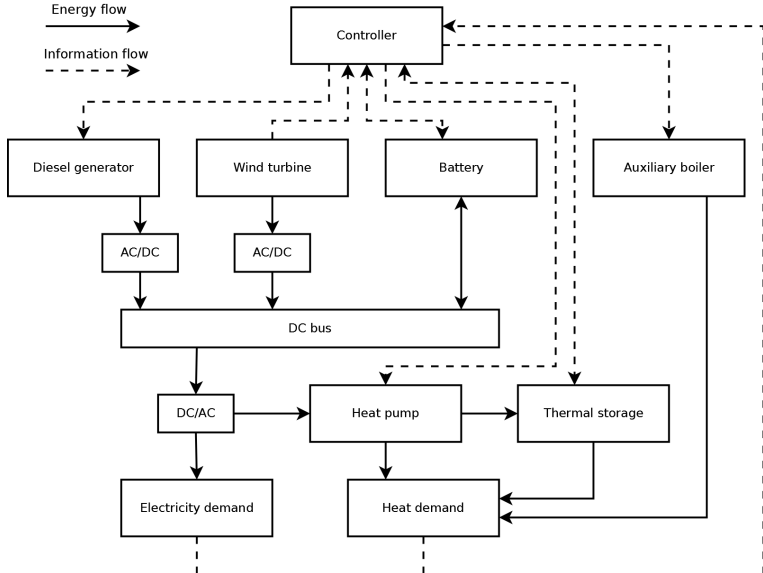
- Diesel generators provide electricity in many remote locations
- Heat and hot water is generated by gas, oil or biomass boilers
- Dependency on imported and expensive fossil fuels
  - high energy, i.e. electricity and heat, prices
  - emissions of greenhouse gases
- Hybrid energy systems can actively contribute to the reduction of local imports



From Remote Islands Grids to Urban Solar Co-Operatives: Community power Scotland, Friends of the Earth Scotland, 2014.

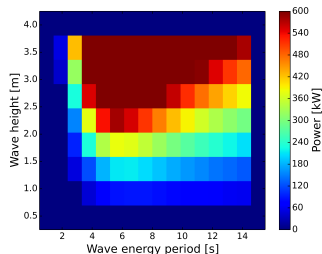


# HEATS: Hybrid Electricity And Thermal System



# Why not Homer?

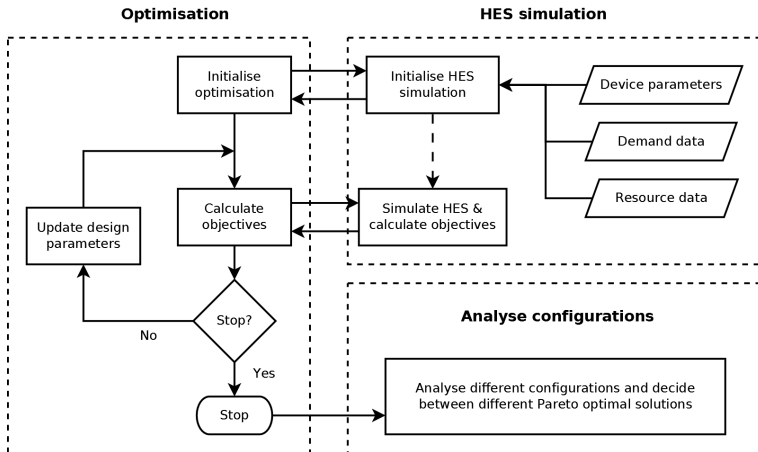
- Focused on hybrid electricity systems
  - Limited options to include heat pumps and thermal energy storage
- No multi-objective optimisation
- No wave energy converter



L. Marquis et al, Introduction of Wavestar Wave Energy Converters at the Danish offshore wind power plant Horns  
Rev 2, 4th Int. Conf. Ocean Energy, 2011

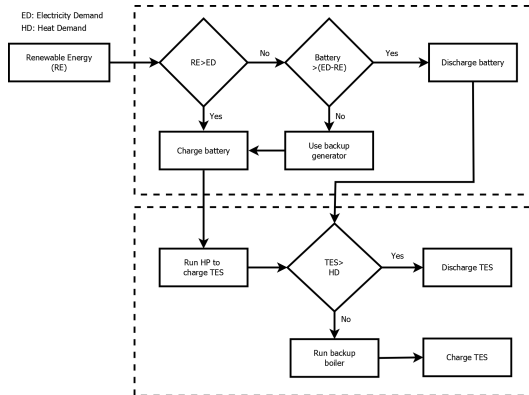


# Optimisation framework



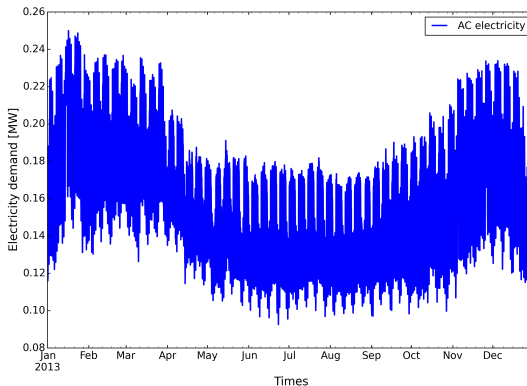
# HEATS input and control

- Commodity: resources, demands and intermediaries
- Units: type of energy converters and storages
- Connections: originating unit, commodity and receiving unit
- Demands: demand profiles
- Resources: renewables and fossil fuels



# Case study - electricity demand

- Community of 335 domestic buildings in the North of Scotland
- Electricity demand profile from UK profile scaled to 335 properties
- Annual electricity demand 1480 MWh

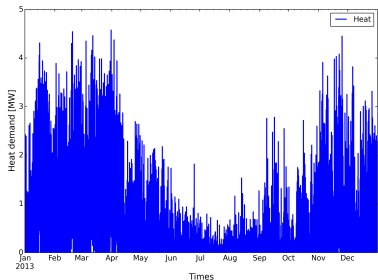


Data from National Grid and <http://www.gridwatch.templar.co.uk>

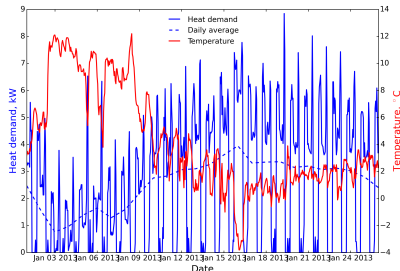


# Case study - heat demand

- Heat demand for 335 domestic properties from temperature profile, UK average annual demand and a distribution of occupancy profiles
- Annual heat demand 4643 MWh



Total heat demand



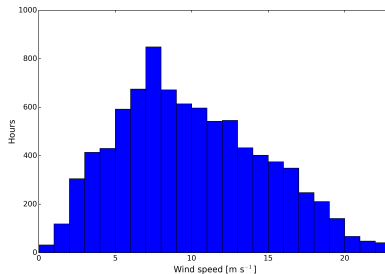
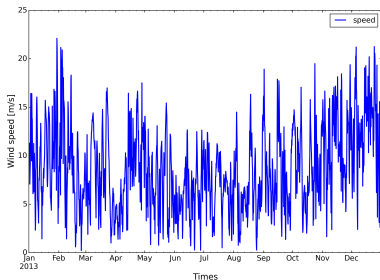
Single property demand for 3 winter weeks

Renaldi et al. Optimisation of Thermal Energy Storage Integration in a Residential Heating System, SusTEM 2015, Newcastle, UK, 2015, p. 131.



# Case study - wind resource

- Wind speed at 10 metre hub height for Orkney
- Use power law to calculate wind speed at hub height (35m)



# Energy system case studies

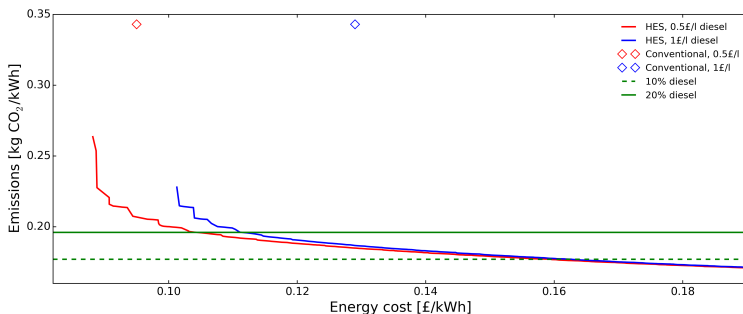
- ❶ Electricity from diesel generators and heating from gas boilers
- ❷ Hybrid electricity system and gas boilers
- ❸ Hybrid electricity and heating system with backup

## Case 1: fossil fuel electricity and heat

- Costs
  - Electricity cost  $0.148 \text{ £ kWh}^{-1}$  for a diesel cost of  $0.5 \text{ £/l}$
  - Electricity cost  $0.292 \text{ £ kWh}^{-1}$  for a diesel cost of  $1 \text{ £/l}$
  - Heating cost  $0.078 \text{ £ kWh}^{-1}$
  - Combined energy costs  $0.128 \text{ £ kWh}^{-1}$  for a diesel cost of  $1 \text{ £/l}$
- Emissions
  - $0.779 \text{ kg}_{\text{CO}_2} \text{ kWh}_{\text{el}}^{-1}$  or 1153 tons of  $\text{CO}_2$
  - $0.208 \text{ kg}_{\text{CO}_2} \text{ kWh}_{\text{th}}^{-1}$  or 965 tons of  $\text{CO}_2$
  - Total emissions of  $0.343 \text{ kg}_{\text{CO}_2} \text{ kWh}^{-1}$  or 2118 tons of  $\text{CO}_2$
- Strong dependence on fuel costs



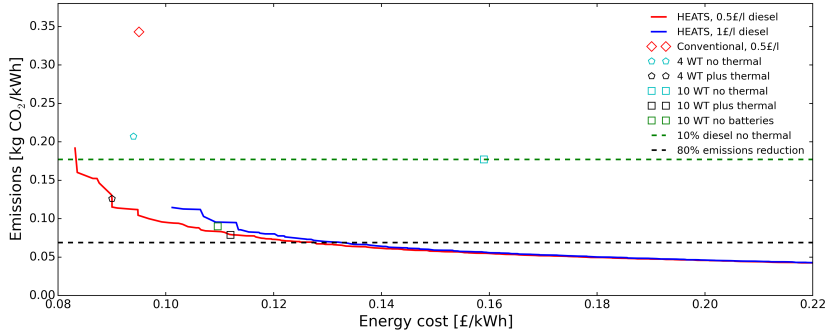
## Case 2: Hybrid electricity and fossil fuel heat



- Configuration for  $\approx 20\%$  diesel:
  - 6 wind turbines and 230 kWh of battery storage
  - Dumped renewable electricity 3516 MWh
- Configuration for  $\approx 10\%$  diesel:
  - 10 wind turbines and 1480 kWh of battery storage
  - Dumped renewable electricity 6441 MWh
- Same energy cost: 4 wind turbines and 150 kWh storage gives  $0.207 \text{ kg CO}_2 \text{ kWh}^{-1}$  or 26% diesel contribution



# Case 3: Full hybrid electricity and heat with backup



- Integration of electric and thermal loads improves the utilisation of the renewable resource
- Not all of the renewable electricity and heat is used
  - Integrate power-to-gas or liquid
  - Seasonal heat storage
  - Potential for PCM and thermochemical TES





# Conclusion

- Deep decarbonisation is a significant challenge
- Combining different resources and demands can help to reduce the fossil fuel fraction
- Integration of electricity and heat (and transport) has large potential to increase the utilisation of the variable resource
- Future energy systems require the integration of electricity and heat with storage
- Thermal storage energy capacity is an order of magnitude cheaper and should be part of the energy system

## Acknowledgements

Thanks to my students Jonathan Fallman, Renaldi and George Lavidas.

## Thank you for your attention!



### OSes 2016

Offshore Energy & Storage Symposium

**13-15 July 2016**  
**The University of Malta**  
**oses2016.com**

- Sessions on energy storage, offshore renewables, smart grids, islands networks, and more
- Delegates from around the world

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# HES equipment

- Vestas V27 wind turbine: hub height 35 m; rated power 225 kW; cut-in, rated and cut-out speed of 3.5, 14 and 25 m/s
- Perkins 175 kW diesel generator: hourly diesel consumption at rated capacity is 48 litres
- Battery storage at  $600\text{£ kWh}^{-1}$
- Mitsubishi Ecodan 8.5kW air source heat pump
- Gas boiler with 90% efficiency
- Domestic hot water storage tanks

